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Indian Standard

SPECIFICATION FOR HEAT RESISTANT ALLOY STEEL AND NICKEL BASE CASTINGS

(Second Revision)

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Indian Standard

SPECIFICATION FOR HEAT RESISTANT ALLOY STEEL AND NICKEL BASE CASTINGS

(Second Revision)

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Indian Standard

SPECIFICATION FOR HEAT RESISTANT ALLOY STEEL AND NICKEL BASE CASTINGS

(Second Revision)

0. FOREWORD

0.1 This Indian Standard (Second Revision) was adopted by the Indian Standards Institution on 30 May 1986, after the draft finalized by the Steel Castings Sectional Committee had been approved by the Structural and Metals Division Council.

0.2 This standard was first published in 1968 and was subsequently revised in 1979. In the present revision, the following main modifications have been made:

a) Amendment No. 1 of March 1983 has been suitably incorporated.

b) New clause for residual elements has been incorporated.

c) Various clauses concerning to chemical composition, non-destructive testing and repair of castings have been aligned with the recent standard on steel castings.

0.3 Particulars to be specified by the purchaser while ordering steel castings according to this specification have been given in Appendix A.

0.4 Heat resistant alloy steel castings are used for service at elevated temperatures in various industries such as aircraft, cement, chemical, petroleum refining, furnace and power plants. The alloy combinations of these castings are resistant to oxidation and corrosion at elevated temperatures. The addition of molybdenum, tungsten and cobalt improves the properties of these alloys at elevated temperatures.

0.5 For the guidance of engineers and designers typical mechanical properties of various grades of heat resistant alloy steel castings and the general information regarding their use have been given in Appendices B and C. Data for Grades 1, 2, 3 and 8 will be added when available. The typical properties given are for information only. If the purchaser requires any mechanical properties to be guaranteed, the same is subject to agreement with the supplier at the time of enquiry and order.

0.6 In the formulation of this standard, assistance has been derived from ASTM Designation : A-297-1976 Specification for heat resistant iron chromium and iron chromium nickel alloy castings for general applications prepared by the American Society for Testing and Materials.

0.7 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard covers the requirements for iron chromium and iron chromium nickel alloy castings for heat resistant service for use at temperatures 600 to 1 100°C.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 **Cast (Melt)** — The product of any one of the following:

a) One furnace heat,

b) One crucible heat, or

c) A number of furnance or crucible heats of similar composition mixed in a ladle or tapped in separate ladles and poured simultaneously for making a casting.

2.2 **Batch** — A group of castings of one grade of material, cast from the same melt and heat treated together under identical conditions.

3. SUPPLY OF MATERIAL

3.1 General requirements relating to the supply of heat resistant alloy steel castings shall conform to IS : 8800-1986†.

4. GRADES

4.1 Heat resistant alloy steel castings shall be of fourteen grades (*see* Table 1).

---

*Rules for rounding off numerical values (*revised*).

†Technical delivery conditions for steel castings (*second revision*).

TABLE 1 CHEMICAL COMPOSITION OF HEAT RESISTANT ALLOY STEEL CASTINGS

(*Clauses* 4.1, 6.1, 6.2 *and* 6.3.1)

Constituent	Requirement, Percent													
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Grade 13	Grade 14
Carbon	0·40 *Max*	0·30 to 0·60	1·20 to 1·40	0·20 to 0·50	0·20 to 0·50	0·20 to 0·50	0·20 to 0·50	0·15 to 0·35	0·20 to 0·50	0·20 to 0·60	0·20 to 0·50	0·35 to 0·75	0·35 to 0·75	0·35 to 0·75
Silicon, *Max*	2·00	2·00	2·00	2·00	2·00	2·00	2·00	2·50	2·00	2·50	2·00	2·50	2·50	2·50
Manganese, *Max*	1·00	1·00	1·00	1·00	2·00	2·00	2·00	1·50	2·00	2·00	2·00	2·00	2·00	2·00
Chromium	12·0 to 14·0	27·0 to 30·0	27·0 to 30·0	26·0 to 30·0	18·0 to 20·0	26·0 to 30·0	23·0 to 27·0	19·0 to 21·0	23·0 to 27·0	28·0 to 32·0	19·0 to 23·0	13·0 to 17·0	17·0 to 21·0	15·0 to 19·0
Nickel	1·0 *Max*	—	—	4·0 to 7·0	8·0 to 10·0	8·0 to 10·0	11·0 to 14·0	13·0 to 15·0	18·0 to 22·0	18·0 to 22·0	23·0 to 27·0	33·0 to 37·0	37·0 to 41·0	64·0 to 68·0
Molybdenum, *Max*	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5	0·5
Sulphur, *Max*	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050
Phosphorus, *Max*	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050	0·050

NOTE 1 — Restricted ranges for various elements within the limits stipulated above may be ordered if agreed to at the time of enquiry and order.

NOTE 2 — Grade 7 may be manufactured in two types (*see* Appendix C).

5. MANUFACTURE

5.1 The steel for the castings shall be made by electric arc or electric induction or such other processes as may be agreed to between the purchaser and the manufacturer.

6. CHEMICAL COMPOSITION

6.1 The ladle analysis of steel when carried out either by the method specified in IS : 228* and its relevant parts or any other established instrumental/chemical methods shall be as given in Table 1. In case of dispute the procedure given in IS : 228* and its relevant parts shall be the referee method. However, where the method is not given in IS : 228* and its relevant parts, the referee method shall be agreed to between the purchaser and the manufacturer.

6.1.1 In the interest of uniform welding the limit for copper as 0·30 percent, *Max* may be specified by the purchaser.

6.1.2 The manufacturer shall carry out analysis from a sample of each melt of steel and, if so specified by the purchaser at the time of enquiry and order, shall supply a test certificate of chemical analysis of the sample of steel for each melt.

6.2 **Product Analysis** — If specified at the time of enquiry and order, the product analysis shall be carried out from a broken tensile test piece or from a casting representing each melt. Drillings for analysis shall be taken not less than 6 mm beneath surfaces and in such manner not to impair the usefulness of any castings selected. The permissible variation in product analysis from the limits specified in Table 1 shall be as given in IS : 6601-1972†.

6.3 Residual Elements

6.3.1 Residual elements specified in Table 1 shall not ordinarily be added to the steel and all reasonable precautions shall be taken to prevent contamination from the scrap to keep them as low as practicable.

6.3.2 Analysis and reporting of analysis in the test certificates for residual elements shall be done only when so specified by the purchaser in the enquiry and order. However, the manufacturer shall ensure that the residual elements are within the limits, when such limits are specified by the purchaser in the enquiry and order.

---

*Methods of chemical analysis of steels (*second revision*) (in various parts).

†Permissible deviations in chemical composition for product analysis of steel castings.

7. WORKMANSHIP AND FINISH

7.1 The castings shall be accurately moulded in accordance with the pattern or the working drawings supplied by the purchaser with the addition of such letters, figures and marks as may be specified.

7.2 The purchaser shall specify the tolerances on all important dimensions. On other dimensions, tolerances specified in IS : 4897-1976* shall apply.

8. FREEDOM FROM DEFECTS

8.1 All castings shall be free from defects that will adversely affect machining and utility of castings.

8.2 When necessary to remove risers by iron powder flame or electric arc cutting, care shall be taken to make the cut at a sufficient distance from the body of the casting so as to prevent any defect being introduced into the casting due to local heating. Any flame or arc cutting which may have to be done shall be carried out before heat treatment.

8.3 In the event of any casting proving defective from foundry causes in the course of preparation, machining or erection, such castings may be rejected notwithstanding any previous certificate of satisfactory testing and/ or inspection.

9. FETTLING AND DRESSING

9.1 All castings shall be properly fettled and dressed, and all surfaces shall be thoroughly cleaned.

10. HEAT TREATMENT

10.1 Unless otherwise agreed to between the purchaser and the manufacturer the castings shall be supplied in as-cast or annealed condition.

10.2 The relevant records of heat treatment shall be furnished to the purchaser, if so specified by the purchaser at the time of enquiry and order.

11. NON-DESTRUCTIVE TEST

11.1 Non-destructive testing shall be applied if specified in the enquiry and order. When specified, the castings shall be examined as follows:

a) Radiographic examination (*see* IS : 2595-1978†),

---

*Deviations for untoleranced dimensions and mass of steel castings (*first revision*).

†Code of practice for radiographic testing (*first revision*).

b) Magnetic particle examination (*see* IS : 3703-1980*).

c) Liquid penetrant examination (*see* IS : 3658-1981†).

d) Ultrasonic examination (*see* IS : 7666-1975‡).

11.2 The location, the percentage of quantity to be examined and the acceptance standard shall be agreed to between the purchaser and the manufacturer. However, in case of ultrasonic examination, liquid penetrant examination and magnetic particle examination IS : 9565-1980§, IS : 11732-1986‖, and IS : 10724-1983¶ respectively shall be taken as the acceptance standards.

11.3 **Microstructure** — In case of austenitic steel castings, if required by the purchaser the maximum permissible percentage of ferrite in the microstructure, shall be stipulated at the time of enquiry and order.

NOTE — The sample for metallographic examination shall be taken from the relevant test block.

11.3.1 The austenitic steel castings shall either be fully non-magnetic or feebly magnetic depending on the actual composition balance within the specified range.

11.3.1.1 If required by the purchaser the permissible degree of magnetism shall be the subject of agreement at the time of enquiry and order.

12. SAMPLING

12.1 The methods of sampling the steel castings for the purpose of chemical analysis and mechanical tests including retest shall be in accordance with IS : 6907-19737**.

13. REPAIR OF CASTINGS

13.1 Unless otherwise specified by the purchaser on the enquiry and order, castings may be rectified by welding without the previous permission of the purchaser.

13.2 All repairs by welding shall be carried out in accordance with the procedure laid down in IS : 5530-1969††. If castings have been subjected to non-destructive testing by agreement between the purchaser and the manufacturer, the casting shall be re-examined in the area of repair following

---

*Code of practice for magnetic particle flaw detection (*first revision*).

†Code of practice for liquid penetrant flaw detection (*first revision*).

‡Recommended procedure for ultrasonic examination of ferritic castings of carbon and low alloy steel.

§Acceptance standard for ultrasonic inspection of steel castings.

‖Acceptance standard for dye penetrant inspection of steel castings.

¶Acceptance standard for magnetic particle inspection of steel castings.

**Methods of sampling of steel castings.

††Code of procedure for repair and rectification of steel castings by metal arc welding process.

AMENDMENT NO. 1 APRIL 1990
TO
IS 4522 : 1986 SPECIFICATION FOR HEAT RESISTANT ALLOY STEEL AND NICKEL BASE CASTINGS

(Second Revision)

(*Pages* 8 *and* 9, *clauses* 13, 13.1, 13.2 *and* 13.3) — Substitute the following for the existing clauses:

'13 REPAIR OF CASTINGS

13.1 Unless otherwise specified by the purchaser in the enquiry and order, castings may be rectified by welding All repairs by welding shall be carried out in accordance with the procedure laid down in IS 5530 : 1986. If castings have been subjected to non-destructive testing by agreement between the purchaser and the manufacturer, the castings shall be re-examined in the area of repair following any rectifying operation performed on the castings.

13.2 To form the basis of an agreement between the purchaser and the supplier in this respect, the following classification shall apply concerning the extent of repair:

a) Weld repair involving a depth not exceeding 20 percent of wall thickness or 25 mm, whichever is lower, shall be termed as a minor repair.

b) Any weld repair exceeding the above shall be termed as a major repair. Further any single repair having an area exceeding 250 mm^2 for every millimetre of wall thickness shall also be deemed to be a major repair, regardless of the considerations mentioned in (a) above.

13.3 **Carbon Equivalent** — Unless otherwise specified in the enquiry and order, or otherwise agreed to, the Carbon Equivalent (C. E.) for the purpose of guidance in determination of the pre- hand post-weld treatment applicable to carbon and low alloy steels shall be computed as follows:

NOTE — In case of high alloy steels the formula for computing Carbon Equivalent shall be subject to agreement between the parties.

$$\text{C. E.} = \text{C} + \frac{\text{Mn}}{6} + \frac{\text{Cr} + \text{Mo} + \text{V}}{5} + \frac{\text{Ni} + \text{Cu}}{15}$$

13.4 The welding procedure to be followed for any welding that may be required on the surface hardened area shall be as agreed mutually.'

(MTD 17)

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any rectifying operation performed on the castings. If specified in the enquiry and order, a record of the weld repair carried out shall be furnished by the manufacturer to the purchaser.

13.3 To form the basis of an agreement between the purchaser and the supplier where relevant, the following classification shall apply considering the extent of repair:

i) Weld repair involving a depth not exceeding 20 percent of the wall thickness or 25 mm, whichever is lower, shall be termed as a minor repair.

ii) Any weld repair exceeding the above shall be termed as a major repair. Further, any single repair having an area exceeding 250 sq mm for every mm of wall thickness shall also be deemed to be a major repair, regardless of the considerations mentioned in sub-para (i).

14. MARKING

14.1 Each casting shall be legibly marked with the following:

a) Grade of the casting,

b) The number or identification mark by which it is possible to trace the melt and the heat treatment batch from which it was made,

c) The manufacturer's initials or trade-mark, and

d) Other identification marks in accordance with the agreement between the purchaser and the manufacturer.

14.2 By agreement between the purchaser and the manufacturer, castings complying with the requirements of this standard shall, after inspection, be legibly marked with an acceptance mark.

14.2.1 The castings may also be marked with the Standard Mark.

14.2.2 The use of the Standard Mark is governed by the provisions of Bureau of Indian Standards Act, 1986 and the Rules and Regulations made thereunder. The details of conditions under which the licence for the use of Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

APPENDIX A

(*Clause* 0.3)

INFORMATION TO BE SUPPLIED BY THE PURCHASER

A-1. BASIS FOR ORDER

A-1.1 While placing an order for the purchase of steel castings covered by this standard the purchaser should specify the following:

a) Material specifications;

b) Drawing or reference number of the pattern (if supplied by the purchaser), along with a copy of the drawing;

c) Tests required;

d) Whether the castings are to be inspected and tested in the presence of the purchaser's representative;

e) Condition of delivery;

f) Any special requirements; and

g) Test reports, if required.

APPENDIX B

(*Clause* 0.5)

TYPICAL MECHANICAL AND PHYSICAL PROPERTIES OF HEAT RESISTANT ALLOY STEEL CASTINGS

Sl No.	Property	Requirement														
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7		Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Grade 13	Grade 14
								Type 1	Type 2							
1.	***Mechanical Properties at Room Temperature***															
	i) Yield strength, MPa:															
	a) As-cast	—	—	—	240	240	290	250	250	—	250	240	240	240	240	220
	b) Aged	—	—	—	—	270	340	290	290	—	290	—	—	270	270	250
	ii) Tensile strength, MPa:															
	a) As-cast	590	390	—	510	490	610	510	510	450	450	460	440	450	450	410
	b) Aged	—	—	—	—	540	570	540	540	—	500	—	—	470	470	440
	iii) Elongation (Gauge length = 5·65 $\sqrt{S_0}$), percent:															
	a) As-cast	8	—	—	7	20	10	15	10	7	10	10	7	5	4	4
	b) Aged	—	—	—	—	15	8	10	7	—	7	—	—	3·5	3·5	4
	iv) Brinell hardness, *HB*:															
	a) As-cast	—	—	—	—	130 to 200	160 to 220	150 to 230	150 to 230	150 to 220	150 to 210	140 to 200	130 to 200	135 to 200	135 to 200	130 to 200
	b) Aged	—	—	—	—	150 to 220	—	160 to 240	160 to 240	—	160 to 220	—	—	145 to 210	145 to 210	140 to 210
	v) Ageing treatment					24 h at 760°C furnace cooled	24 h at 760°C furnace cooled	24 h at 760°C furnace cooled			24 h at 760°C air cooled			24 h at 760°C air cooled	48 h at 980°C air cooled	48 h at 980°C air cooled
2.	***Mechanical Properties at Elevated Temperature:***															
	i) Short-time tensile strength, MPa, at:															
	a) 540°C				—	—	—	—	—	—	—	—	—	—	—	—
	b) 590°C				—	—	—	—	—	—	—	—	—	—	—	—

Sl No.	Property	Requirement														
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7		Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Grade 13	Grade 14
								Type 1	Type 2							
	c) 650°C				—	400	—	—	—	—	—	—	—	300	—	240
	d) 760°C				250	250	—	230	250	—	—	—	340	250	280	—
	e) 870°C				160	150	—	130	150		160	—	210	130	140	140
	f) 980°C				110	—	—	60	70		—	—	130	80	70	70
	g) 1 090°C				—	—	—	—	—		—	—	—	40	—	—
ii)	Short-time yield strength, MPa, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	—	—	—	—		—	—	—	200	—	140
	d) 760°C				—	150	—	120	130		—	—	—	180	—	—
	e) 870°C				—	—	—	90	100		—	—	—	110	—	120
	f) 980°C				—	—	—	40	50		—	—	—	60	40	50
	g) 1 090°C				—	—	—	—	—		—	—	—	—	—	—
iii)	Elongation ($L_o = 5.65 \sqrt{S_o}$), percent, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	14	—	—	—		—	—	—	5	—	8
	d) 760°C				12	18	—	16	11		—	—	—	9	—	—
	e) 870°C				16	20	—	27	14		—	—	—	23	18	46
	f) 980°C				38	—	—	42	27		19	—	—	25	25	40
	g) 1 090°C				—	—	—	—	—		—	—	—	—	—	—
iv)	Creep stress 0·000 1 percent/h, MPa, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	90	—	—	—		82	—	—	—	—	—
	d) 760°C				25	42	28	21	49		48	49	—	56	59	45
	e) 870°C				13	22	17	12	28		30	30	44	32	35	22
	f) 980°C				6	—	10	8	15		19	16	22	14	16	11
	g) 1 090°C				—	—	—	2	6		7	—	6	4	4	4
	h) 1 170°C				—	—	—	—	—		1·4	—	—	1	—	—

SL No.	PROPERTY	REQUIREMENT														
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7		Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Grade 13	Grade 14
								Type 1	Type 2							
	v) Stress to rupture, MPa, 10 h, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	250	—	—	—		—	—	—	—	—	—
	d) 760°C				100	140	—	—	50		160	—	—	—	—	130
	e) 870°C				—	70	—	—	30		77	—	—	77	—	70
	f) 980°C				—	—	—	30	15		50	—	—	41	—	40
	g) 1 090°C				—	—	—	—	6		—	—	—	—	—	20
	h) 1 170°C				—	—	—	—	—		—	—	—	—	—	—
	vi) Stress to rupture, MPa, 100 h, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	210	—	—	250		—	—	—	—	—	—
	d) 760°C				70	100	80	100	100		100	100	—	130	110	90
	e) 870°C				35	40	40	45	50		55	65	70	60	56	50
	f) 980°C				20	—	20	20	30		30	40	30	30	30	25
	g) 1 090°C				—	—	—	10	15		20	—	20	20	—	12
	h) 1 170°C				—	—	—	—	—		—	—	—	—	—	—
	vii) Stress to rupture, MPa, 1 000 h, at:															
	a) 540°C				—	—	—	—	—		—	—	—	—	—	—
	b) 590°C				—	—	—	—	—		—	—	—	—	—	—
	c) 650°C				—	120	—	—	160		—	—	—	—	—	—
	d) 760°C				49	56	—	46	70		63	—	—	88	—	—
	e) 870°C				—	27	—	27	30		35	—	46	49	42	28
	f) 980°C				—	—	—	15	18		21	—	23	26	20	16
	g) 1 090°C				—	—	—	—	8		—	—	6	13	—	6
	h) 1 170°C				—	—	—	—	—		—	—	—	—	—	—
3.	*Physical Properties*															
	i) Density, kg/dm^3				7·58	7·75	7·67	7·72	7·72		7·75	7·72	7·83	7·92	8·03	8·14
	ii) Mean coefficient of linear thermal expansion, cm/°C × 10^{-6}:															
	a) 20-100°C				—	13·0	—	—	—		—	—	—	—	—	—

Sl No.	Property	Requirement														
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7		Grade 8	Grade 9	Grade 10	Grade 11	Grade 12	Grade 13	Grade 14
								Type 1	Type 2							
	b) 20-540°C				13·9	17·8	17·3	16·9	16·9		16·6	16·6	—	15·3	15·8	14·0
	c) 20-590°C				14·4	18·2	17·8	17·5	17·5		16·9	16·9	—	16·0	16·2	14·6
	d) 20-760°C				18·9	18·5	18·4	17·8	17·8		17·3	17·3	—	16·6	16·6	15·3
	e) 20-870°C				15·5	18·7	18·9	18·4	18·4		17·5	17·5	—	16·7	16·9	15·8
	f) 20-980°C				16·0	18·9	19·4	18·9	18·9		18·0	18·0	—	17·6	17·3	16·6
	g) 20-1 090°C				16·6	19·6	20·0	19·4	19·4		18·2	18·2	—	17·6	17·5	17·1
	h) 650-870°C				18·5	20·0	22·0	21·1	21·1		18·9	18·9	—	18·7	18·9	19·3
	j) 850-980°C				19·1	—	22·5	21·8	21·8		20·0	19·3	—	20·7	19·1	20·3
iii)	Specific heat 20°C, cal/g°C				0·12	0·12	0·14	0·12	0·12		0·12	0·12	0·11	0·11	0·11	0·11
iv)	Specific electrical resistance, microhm/cm², at 20°C.				81	80	85	75/85	75/85		91	94	—	100	105	—
v)	Thermal conductivity kcal/m²h (°C/m):															
	a) 100°C				18·7	13·4	—	12·2	12·2		12·2	12·2	—	11·5	—	—
	b) 540°C				26·6	19·9	—	16·2	16·2		16·2	16·2	—	16·9	13·2	—
	c) 815°C				30·2	22·3	14·9	21·3	21·3		17·7	17·7	—	—	—	—
	d) 1 090°C				36·0	25·2	—	24·4	24·4		—	—	—	—	—	—
vi)	Melting point (approx), °C				1 480	1 400	1 450	1 370	1 370		1 400	1 425	1 370	1 340	1340	1 290
vii)	Magnetic permeability				Ferromagnetic	1·00	1·3 to 2·5	1·0 to 1·9	1·0 to 1·9		1·02	1·01	1·10	1·10 to 2·00	1·10 to 2·00	2·0
viii)	Modulus of elasticity, MPa × 10^4				19	20	18	19	19		20	20	19	19	19	18
ix)	Normally used pattern makers shrinkage allowance (mm/m)				18	23·5	23·5	26	26		26	26	26	26	26	23·5

NOTE — Information for Grades 1, 2, 3 and 8 will be included as and when available.

APPENDIX C

(*Clause* 0.5)

CHARACTERISTICS AND TYPICAL USES OF HEAT RESISTANT ALLOY STEEL CASTINGS

C-1. GENERAL CHARACTERISTICS

C-1.1 The heat resistant alloy steel compositions are capable of performing satisfactorily when used at temperatures above 600°C. These alloy compositions are composed principally of nickel, chromium and iron together with the small percentage of other elements. Nickel and chromium both contribute to the superior heat resistance of these alloys. Castings made up of these alloys meet two basic requirements, good surface film stability (oxidation and corrosion resistance) in various atmospheres and at temperatures to which they are subjected, and the required mechanical strength ductility to meet high temperature service conditions.

C-1.1.1 The heat resistant alloy compositions covered by this standard may be broadly classified into the following three groups, based on the composition and metallurgical behaviour:

a) Chromium-iron alloys (containing up to 7 percent nickel)	Grades 1, 2, 3, and 4
b) Chromium-nickel-iron alloy (containing up to 22 percent nickel)	Grades 5, 6, 7, 8, 9 and 10
c) Iron-nickel-chromium alloys (containing more than 22 percent nickel)	Grades 11, 12, 13 and 14

C-1.2 Casting Characteristics — Section thickness over 5 mm is normally cast satisfactorily in all these alloys. This includes a finishing allowance of 3 mm or more on surfaces to be machined. Sometimes thinner sections may also be cast usefully, depending upon casting design and pattern equipment. Drastic changes in sections should be avoided and uniform sections maintained. In general overall dimensional tolerances and location of cored holes may be held to 5 mm per metre. This, however, largely depends on the quality of the pattern.

C-1.3 Welding — All the grades of steel castings covered by this standard may be welded by metal arc, inert gas arc or oxy-acetylene gas methods. Grade 3 castings with carbon content approaching specified maximum is not usually welded. Where welding of this grade is necessary, exceptional care is to be exercised. Preheat-treatment of Grade 2 castings is necessary before welding. Chromium-iron grades of castings are also given proper annealing treatment after welding.

In the welding of all nickel containing grades preheat-treatment or post-weld treatment is not necessary. For high temperature applications metal arc welding is considered more satisfactory in case of chromium-iron alloys. Oxy-acetylene gas welding is more satisfactory in the case of nickel-chromium iron alloys. Lime coated electrodes of similar composition are recommended for arc welding and bare electrodes of similar composition may be used for gas welding. During gas welding the flame should be adjusted to be very rich in acetylene.

C-1.4 Machinability — Although many castings do not require any machining and are used directly after cutting off the gates and risers, some of the jobs may require machining to the finished dimensions. Most of the machining operations may be performed satisfactorily on these alloys. It is, however, important that in all cases, tool is kept continually entering into the metal. Slow feeds, deep cuts and powerful and rigid machines are necessary for best results. Work should be firmly mounted and supported and tool mountings should provide maximum stiffiness. Both high speed steel and carbide tools may be used but use of carbide tools permits operations at higher speeds. Good lubrication and cooling are essential while machining.

C-1.5 Design Characteristics — A design stress of 50 percent of the stress that will produce a creep rate of 0·000 1 percent per hour at the maximum operating temperature is normally suggested. This value, however, is applicable only in conditions of static and direct axial loading and fairly uniform temperature, or gradual temperature variations. Where impact loading or rapid temperature cycle are involved a considerably lower percentage of the limiting creep stress should be used. However, for components which are inaccessible, non-uniformly loaded or of complex design, higher factors of safety should be used, while lower factors of safety are permissible if the parts are fully supported or rotating, simple in design with little or no thermal gradient and are also easily accessible for replacement.

C-2. SPECIFIC CHARACTERISTIC AND TYPICAL USES

C-2.1 Iron-Chromium Alloys — This group of alloys contains up to 30 percent chromium and up to 7 percent nickel. These alloys are predominantly ferritic and, therefore, have relatively low hot strength. They are seldom used in critical load bearing parts at temperatures above 925°C, but are sometimes used in applications involving uniform heating and certain atmospheric conditions, such as high sulphur atmospheres.

C-2.1.1 *Grade* 1 — This is a chromium-iron alloy with just sufficient chromium to provide resistance to oxidation up to about 900°C. The structure is mainly ferritic and may be varied by heat treatment. Castings in this alloy are normally supplied in the annealed condition. Annealing is carried out on 800 to 850°C followed by furnace cooling.

Some typical applications of this grade of castings include furnace parts with low mechanical stress, for example, hearth plates, door frames, refinery fittings, etc.

C-2.1.2 *Grade* 2 — There is a chromium-iron alloy with high chromium conferring excellent resistance to oxidation and high sulphur flue gases up to about 1 150°C. Its application is, however, generally limited to items where strength is not a consideration, as the room temperature ductility, and impact strength and creep strength at elevated temperatures are low. The structure consists of ferrite and carbides. The alloy is not capable of being hardened by heat-treatment. Annealing is generally carried out of 700 to 800°C followed by furnace cooling.

Typical applications of this grade of castings include furnace grate bars, incinerating retorts, kiln parts, parts of cement kiln, burner nozzles, tuyeres, etc.

C-2.1.3 *Grade* 3 — This grade of steel castings is similar to Grade 2 castings, but with a higher hardness. It is particularly suitable for casting subjected to high degree of wear at high temperature, such as stirring blades. Its impact strength is lower than Grade 2 material. The structure consists of ferrite and carbides and the alloy is not hardenable.

C-2.1.4 *Grade* 4 — This is essentially a chromium-iron alloy with some addition of nickel. It possesses the best hot strength and high temperature corrosion resistance among the chromium-iron alloys The structure consists of both ferrite and austenite and the alloy is not hardenable. However, long exposures on the temperature range of 700 to 800°C may lead to hardening together with some loss of room temperature ductility due to formation of sigma phase. Ductility may be restored by heating uniformly to about 980°C or above and rapid cooling to below 650°C. Castings in this alloy are normally supplied in the as-cast condition.

The alloy is suitable for high sulphur atmospheres and may be used for load bearing applications up to 650°C and light loads up to 1 000°C. Typical applications include furnace rabble arms and blades, salt pots and cement kiln parts.

C-2.2 **Chromium-Iron-Nickel Alloys** — These alloys are characterized by good high temperature strength, hot and cold ductility and resistance to oxidizing and reducing conditions. They are useful for atmospheres high in sulphur particularly under reducing conditions. These alloys contain 18 to 30 percent chromium and 8 to 22 percent nickel and may have either a partial or complete austenitic structure.

C-2.2.1 *Grade* 5 — This is a chromium-iron-nickel alloy comparable to the popular wrought 18/8 stainless steel with substantially more carbon. It is suitable for applications requiring high strength and corrosion resistance at 650 to 850°C. The as-cast structure of the alloy consists of an austenitic matrix containing interdendritic eutectic carbide and occasionally an unidentified lameller constituent. With unbalanced compositions, the as-cast structure may be partially ferritic. Such a structure is susceptible to sigma embrittlement after long exposure in the temperature range of 750 to 850°C. Castings in this grade are usually supplied in the as-cast condition. In service conditions involving thermal fatigue arising from rapid heating and cooling, improvement in performance may be obtained by heating the castings to above 1 050°C and holding them for 6 hours followed by furnace cooling prior to placing in service.

Typical applications include burnishing and coating rolls, furnace dampers, annealing furnace parts, etc.

C-2.2.2 *Grade* 6 — This is a chromium-nickel-iron alloy possessing moderate strength, good ductility and excellent corrosion resistance at high temperature. It is the strongest material in high sulphur atmospheres at high temperatures. The alloy has a two-phase austenite plus ferrite structure containing carbides and is non-hardenable. Long exposures around 815°C may lead to hardening along with some phase. Ductility may, however, be restored to a certain extent by quenching the alloy from about 1 080°C. Castings in this grade are normally supplied in the as-cast condition.

This grade is suitable for operations at temperatures up to about 1 075°C. As the alloy has excellent high temperature corrosion resistance in high sulphur atmospheres, it is widely used in ore roasting equipment. Some other typical applications include parts, such as conveyors in furnaces, recuperators and tube support castings.

C-2.2.3 *Grade* 7 — This alloy contains minimum quantities of chromium and nickel required to impart a useful combination of properties for elevated temperature service. The chromium present confers scaling resistance up to about 1 075°C and the nickel present together with carbon, nitrogen and manganese helps to ensure austenite as the predominant phase. However, micro-structure is sensitive to composition balance. Within the stated composition range two types, namely, Types 1 and 2, are generally recognized depending upon the micro-structure. Assuming the usual silicon, manganese and nitrogen contents present in practice, chromium and nickel in the ratio:

$$\frac{\text{Cr percent} - 16 \times \text{C percent}}{\text{Ni percent}} < 1{\cdot}7$$

will maintain a predominantly austenitic phase. Type 1 is partially ferritic (magnetic permeability 1·0 to 1·9) and Type 2 is predominantly austenitic (magnetic permeability 1·00 to 1·05). Type 1 is preferred where ductility is more important than hot strength and where welding is involved. This type is prone to room temperature embrittlement if held for prolonged periods around temperatures of 750 to 875°C due to precipitation of carbides and sigma formation respectively. This would suggest that perhaps the best operating temperature for Type 1 is 925 to 1 075°C. For service in the temperature range 650 to 1 000°C subject to high constant load, Type 2 is preferred because of its high creep strength.

Castings in this grade are normally supplied in as-cast condition. An annealing treatment consisting of holding the castings for about 12 hours at about 1 050°C followed by furnace cooling sometimes improves the performance of the alloy with a medium carbon content (say 0·3 percent) under conditions involving thermal fatigue.

This composition is suitable for a wide range of high temperature applications. Some typical applications of the alloy include furnace shafts, beams, rails and rollers, tube supports and lime and cement kiln parts. It is, however, rarely used for carburizing applications because of embrittlement caused by absorption of carbon. It is also not generally preferred where cyclic service is involved as in quenching fixtures.

C-2.2.4 *Grade* 8 — This is chromium-nickel-iron alloy containing 19 percent chromium and 13 percent nickel. The higher nickel content ensures a stabler austenite. Castings in this alloy are normally supplied in the as-cast condition.

This alloy is chosen where high mechanical strength is involved. Typical applications include parts of continuous furnace, like hearth rails transport grid, cast case hardening boxes, worm retorts, parts for cracking furnaces and hearth rollers.

C-2.2.5 *Grade* 9 — This is somewhat similar to Type 2 of Grade 7 castings in respect of general characteristics and mechanical properties. Higher nickel content ensures stabler austenite. After ageing at service temperature the alloy exhibits precipitation of fine granular carbides within the austenite grains which agglomerate if the temperature is sufficiently high. These fine dispersed carbides contribute to the creep strength of the alloy. Unbalanced compositions are also possible in this alloy particularly around a carbon level of about 0·2 percent giving rise to the presence of ferrite in the austenite matrix which may transform to the brittle sigma phase when held at about 815°C even for relatively short periods. Castings in this alloy are normally supplied in the as-cast condition.

This alloy is chosen where higher creep strength at temperature up to 1 150°C is required. Typical applications include gas turbine parts, furnace parts, such as door arches, lintels, brazing fixtures, cement kiln parts, pier caps, rabble arms and blades, radiant tubes, retorts and stack dampers.

C-2.2.6 *Grade* 10 — This alloy has excellent resistance to oxidation at temperatures over 1 050°C, and is resistant to corrosion in flue gases containing a moderate amount of sulphur up to 980°C. It is used where higher strength is required than obtainable with lower nickel content alloys. Important applications include radiant tubes, furnace skids, and stack dampers where excessive scaling should be avoided, such as in enamelling furnace carriers and fixtures.

C-2.3 Nickel-Chromium-Iron Alloy — These alloys are fully austenitic and contain 23 to 68 percent nickel and 13 to 23 percent chromium. Since no brittle phase is formed in these alloys at elevated temperatures they may be used satisfactorily up to 1 150°C. They have good weldability and with proper tools and coolants are readily machined. They possess hot strength carburization resistance and thermal fatigue resistance. They are used widely for load bearing applications and for castings subjected to cyclic heating and large temperature differentials. They may withstand oxidizing and reducing atmosphere satisfactorily, but high sulphur atmosphere should be avoided.

C-2.3.1 *Grade* 11 — This alloy has sufficient chromium to give good high temperature corrosion resistance. It has essentially an austenitic structure with carbide areas in the as-cast condition. Additional fine carbides precipitate on ageing at service temperature. The alloy is not susceptible to sigma formation. A higher carbon content also does not impair ductility. Castings in this grade are usually supplied in the as-cast condition.

The alloy is reported to have given satisfactory service in several special applications particularly in brazing fixtures at temperatures of 1 100 to 1 150°C. Other possible applications include furnace beams, pier caps, radiant tubes and tubes supports, torch nozzles and trays.

C-2.3.2 *Grade* 12 — This composition has an alloy content almost normally equal to iron content. Because of its high nickel content it possesses adequate resistance to carburization and thermal shock. Large carbide areas are formed at the grain boundries in the as-cast condition. Fine carbides are precipitated within the grain boundries on ageing at sarvice temperature with subsequent loss of room temperature ductility. Such changes in structural constituents after service at high temperature or exposure to carburizing atmospheres may also affect significantly the magnetic properties of the alloy. Higher carbon contents do not vitally affect the high temperature ductility of the alloy, a property which makes the alloy very useful for applications such as carburizing fixtures and containers. By raising the silicon content of the alloy above 1·6 percent the carburization resistance is further increased with some sacrifice of hot strength.

Castings in this alloy are normally supplied in the as-cast condition. The alloy is non-hardenable. For applications involving thermal fatigue arising out of repeated heating and cooling, improvement in performance may be obtained by heating the castings at 1 050°C for 12 hours followed by furnace cooling prior to placing in service.

This is an important and very widely used nickel-chromium-iron alloy. Typical applications include load-bearing members in many furnace applications, retorts, radiant tubes, cyanide, lead and salt pots, hearth plates and trays quenched with the work.

C-2.3.3 *Grade* 13 — This alloy is simiar to Grade 11 in many respects, such as strength at high temperatures, resistance to carburization and thermal fatigue, as-cast and aged micro-structure and fabricating characteristics. However, higher chromium and nickel contents confer greater resistance to corrosion in both oxidizing and reducing atmospheres and make the alloy better suited for applications where severe service conditions arising out of high stress and rapid thermal cycling are involved. Castings in this grade are usually supplied in the as-cast condition. For applications involving thermal fatigue arising out of rapid heating and cooling, improvement for about 12 hours followed by a furnace cooling prior to placing in service.

Typical applications include salt pots, quenching trays, fixtures and gas dissociation equipment.

C-2.3.4 *Grade* 14 — High nickel content in this grade confers high resistance to hot gas corrosion even in the presence of some sulphur and permits it to be used for severed service applications where corrosion should be minimized at temperature up to 1 150°C. It is used to great advantage where maximum and widely fluctuating temperatures are encountered because of its ability to withstand cycling without cracking or severe warping. The most important application of this alloy is, therefore, for quenching fixtures. It is also useful in carburizing and cyaniding equipment. Typical applications in which it gives excellent service include nitriding, carburizing and hardening fixtures (quenched with the work), heat-treating boxes retorts and burner parts.

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